Chapter 1

Introductory Chapter: The Impression of Light-Emitting Diodes in Space-Age Advancements and Its Effect of Blue LED Irradiation

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Additional information is available at the end of the chapter

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1. A succinct evidence of light-emitting diode

Amid the supreme contemporary machineries in lamps and lighting devices, Light-emitting diodes (LEDs) have an enormous amount of novel applications day by day, and flattering ever more prevalent and manageable to the societal benign. Basically, the LED is connected to direct current which emits light in the visible region of spectrum. While experimenting with silicon carbide (crystal detectors) and a cat's whisker, the first discovery of electroluminescence phenomenon using light emitting diode was noticed back at the beginning of the twentieth century (1907), by a British radio engineer H J Round and the assistant to Guglielmo Marconi [1, 2]. In 1927, the phenomenon of electroluminescence in the diodes used in radio sets was studied by a Russian radio researcher Oleg Vladimirovich Losev. Also a credit toward his research, he has published a paper named Luminous carborundum [silicon carbide] detector and detection with crystals [3]. At room (298 K), low (77 K) temperature and even in other semiconductor alloys, the infrared emission was observed by employing the simple diode structures with indium phosphide (InP), silicon-germanium (SiGe), gallium arsenide (GaAs), and gallium antimonide (GaSb) alloys by Rubin Braunstein in 1955 [4]. Years later in the fall 1961, the first infrared LED was invented and patented by Robert Biard and Gary Pittman [5–7]. In 1962, the first visible red LED was invented by Nick Holonyack, using gallium arsenide phosphide (GaAsP) as a substrate for the diode [8]. By employing gallium arsenide phosphide in the diode, the first yellow LED was invented by M George Craford in 1972 [9]. In 1968, the Monsanto Company was the leading group of institution has made a mass-production of visible red LEDs as indicators using gallium arsenide phosphide (GaAsP). Nevertheless, it was not in anticipation of the 1970s that LEDs befitted popular as soon as Fairchild Optoelectronics instigated manufacturing the low-cost LED devices [10]. In 1976, Thomas P. Pearsall invented a new semiconductor LED materials to be used in fiber optics and telecommunication systems with tremendously bright and high efficiency [11]. In 1979, first blue LED using gallium nitride (GaN) was designed by Shuji Nakamura of Nichia Corporation. By dint of creative techniques, the Fairchild Optoelectronics have made LED into profitable manufactured goods with diversity of usages based on packaging and a planar process of chip production. [5–8].

Among the utmost topical technological advancements in lamps lighting devices, LEDs have enormous amount of application niches. Day by day, LEDs are flattering more attractive and more accessible to the common people. For the past few decades semiconductor technology has progressed to greater statures. The result is in the form of smart gadgets and the LEDs which give enhanced illumination with low power ingesting and better life span too.

The LED can be lingering further into three major categories are: (1) traditional inorganic LEDs, (2) organic LEDs (small molecule OLED, polymer LED, passive matrix OLED, active matrix OLED), (3) high brightness LEDs. Further, **Table 1** provides the detailed information about the historical developments in LED and OLED [1–55].

Traditional Inorganic LEDs: By employing various inorganic materials, the traditional type LEDs are made and therefore called as inorganic LEDs. A number of extensively used LEDs have been fabricated using semiconductor materials like aluminum-gallium arsenide (AlGaAs) and indium-gallium nitride (InGaN). Furthermore, with different doping concentrations in inorganic semiconductor material, the traditional inorganic LEDs are used nowadays. These are obtainable in souk with various sizes, shapes and colors like single color LED, surface mounted LED, flashing LED and multicolor LED.

Organic LEDs: Using organic materials, the organic LEDs have been fabricated, which are fictitious from carbon-based polymers and semiconductors. Organic light-emitting diode (OLED) is a thin film of organic compound which consists of a PN junction made by an emissive electroluminescent layer. Further, the emissive layer emits light in Ref. to an electric current and this layer of organic material is positioned among two electrodes. In general, it is realized that as a minimum one of the electrodes must be a transparent one. The organic LEDs are factory-made in the form of thin films; hence, these are given that a small portion for diffusion through which the light engenders, and these can be used for larger surface area. Furthermore, the OLEDs are available in the form of small molecule OLED, polymer LED, passive matrix OLED, and active matrix OLED.

High brightness LEDs: This type of high brightness (HB) comprises both inorganic and organic LEDs, and these are broadly employed for lighting applications. In essence, this type of LEDs is nearly similar as organic LEDs; however, these HBLEDs could produce a very high brightness of light output with respect to the OLEDs. For engendering high brightness, these LEDs require a high current and high-power debauchery; as a result, these LEDs were kept on the heat sink for eradicating the liberation of unnecessary heat.

All these three types have found enormous progresses in their light output in recent years. However, the normal quantum yield is exceeding 100 lm/W for the inorganic

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Light-emitting diode (inorganic LED)			**Organic light-emitting diode (OLED)**		
Year	Historical development	Ref.	Year	Historical development	Ref.
1907	The first discovery of electroluminescence phenomenon using light emitting diode were noticed back at the beginning of the twentieth century, was discovered by a British radio engineer *H J Round* and assistant to *Guglielmo Marconi* while investigating with silicon carbide (crystal detectors) and a cat's whisker	[1, 2]	1950 to 1955	André Bernanose and coconspirators at Université de Nancy, France, consummate the first innovations of electroluminescence in organic materials. By applying the high alternating voltages in air to materials for instance acridine orange (*N*,*N*,*N*′,*N*′-Tetramethylacridine-3,6-diamine), whichever set down on or melted on the thin film layer of cellophane or cellulose. The mechanism put forward of any kind of excited electrons or direct excitation of the dye molecules.	[30–33]
1927	A Russian radio researcher *Oleg Vladimirovich Losev* was experimenting the phenomena of electroluminescence (dealing with the emission spectrum of light radiation in regard to the current–voltage physiognomies of SiC cat's whisker diodes) in the diodes especially employed in radio sets. He has inquisitively published an article called Luminous carborundum [silicon carbide] detector and detection with zincite & iron glance crystals.	[3, 4]	1960	From New York University, Martin Pope and few of his accomplices fabricated the ohmic dark-injecting electrode contacts to organic crystals. These acquaintances are the root of injection of charges in all contemporary OLED gadgets.	[34, 35]
1935	The French physicist Georges Destriau discovers light emission (electroluminescence) in zinc sulfide. Further the effect can be called as "Lossew Light".	[5–8]	1963	Pope's group as well first perceived direct current (DC) electroluminescence under vacuum on a single pure crystal of anthracene and on anthracene crystals doped with tetracene based on a lesser area silver electrode at 400 V under the process of field-accelerated electron excitation of molecular fluorescence.	[36]
1939	Zoltan Bay together with Gyorgy Szigeti received a U.S. patent on "Electroluminescent light sources" which were made of a lighting device using SiC, with an possibility on boron carbide (BC), that emitted white, yellowish white, or greenish white contingent on impurities present; these light sources were the ancestors of light-emitting diodes (LEDs).	[5–8]	1965	Pope's group described the nonoccurring of an external electric field, the recombination of a thermalized electron and hole electroluminescence mechanism can be instigated on anthracene crystals, and as a result the conducting level of anthracene dwell in the higher energy than the energy level of exciton.	[37]
1951	After the discovery of transistor, Shockley and his collaborators Howard Briggs and James Haynes applied for manifest on infrared LED by employing Germanium and Silicon.	[5–8]	1965	For the first time, W. Helfrich and W. G. Schneider developed the double-injection recombination electroluminescence in an anthracene single crystal by the usage of hole and electrons injection electrodes.	[38]

Light-emitting diode (inorganic LED)			Organic light-emitting diode (OLED)		
1952	Kurt Lehovec and his research team have applied for a patent aimed at SiC diodes that emit light. The research team has grown n-type SiC doped with arsenic and then literally acquaints using boron with a beam of electron to produce p-SiC for the junction.	[5–8]	1965	Dow Chemical patented a method of preparing electroluminescent cells using the mechanism of electronic excitation at the contacts between the graphite particles and the anthracene molecules.	[39]
1955	Rubin Braunstein observed infrared emission generated by simple diode structures using gallium antimonide (GaSb), GaAs, indium phosphide (InP), and silicon-germanium (SiGe) alloys at room (298 K) and at low (77 K) temperature and even in other semiconductor alloys as well.	[9]	1975	Roger Partridge patented the first observation of electroluminescence from polymer films and his device contained of a thick film of poly(N-vinylcarbazole) equal to 2.2 micrometers located among two charge injecting electrodes and further the work got consequently published in 1983.	[40–44]
1958	Rubin Braunstein and Egnor Loebner, working at Radio Corporation of America (RCA) patented a green LED made from lead antimonide (PbSb) dot amalgamate to p-type Germanium (Ge).	[10]	1987	Ching W. Tang and Steven Van Slyke at Eastman Kodak develop the first practical OLED device. This device utilized a two-layer structure with distinct electron and hole transporting layers such that the light emission through recombination process can happen in the intermediate of the organic layer; this would yield in the enhancement in efficiency and a decline in operating voltage.	[45]
1961	James Robert Biard and Gary Pittman invented the infrared radiation from GaAs when electric current is applied and patented a first infrared LED.	[11–13]	1990	J. H. Burroughes *et al.* reported a research on high efficiency green light-emitting polymer-based device by employing poly(p-phenylene vinylene) with a film thickness of 100 nm.	[46]
1962	Nick Holonyack (regarded as Father of LED) invented the first practical visible spectrum of red LED with high efficiency by using gallium arsenide phosphide (GaAsP) as a substrate for the diode.	[14]	1994	Universal Display Corporation (UDC) is a developer and manufacturer of organic light emitting diodes (OLED) technologies (profitable for phosphorescent-based OLEDs and also respective supple, stacked and transparent OLEDs) and materials in regard to the supplier of services to the display and lighting industries.	[47]
1968	MONSANTO Company becomes the first organization to churn out visible red LEDs based on gallium arsenide phosphide (GaAsP).	[5–8]	1998	As an additional advantage the printable and flexible displays were developed using Polymer LEDs.	[48]
1970	FAIRCHILD Optoelectronics (Part of Monsanto Electronic Materials Group) produce commercially successful LEDs.	[5–8]	2004	The potential advantages of OLEDs include thin, cost effective displays along with high contrast, color gamut, low driving voltage, and widespread observing angle.	[49]

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Light-emitting diode (inorganic LED)			Organic light-emitting diode (OLED)		
1971	By employing gallium nitride the first blue LED was developed by Jacques Pankove.	[15]	2008	The organic materials could be considered as small organic molecules in a crystalline phase, or polymers. OLEDs could be widely employed to create display imaging for portable electronic devices like mobile phones, MP3 players, and digital cameras, while conceivable for imminent uses comprise televisions and lighting applications.	[50]
1972	M George Craford invented the first yellow LED using gallium arsenide phosphide (GaAsP) in the diode with an enhanced illumination of red and LEDs with red-orange emission by factors of ten.	[16]	2013	Zhenan Bao et al., have evaluated an innovative approach to develop a large-area organic semiconductor thin film with highly oriented single crystalline domains.	[51]
1974	Stevenson published a patent, reveals a category of gallium nitride (GaN) LED that illuminates light in the visible (violet) region of the spectrum. By employing organic and inorganic phosphors GaN LED may convert lower frequencies (lower energy) with good conversion efficiency. Further he suggests, by employing dissimilar phosphors, all the primary colors may be prepared from this similar basic device."	[17]	2015	Consequent researches have been technologically advanced on polymer-based multilayer device, plastic electronics, production of novel OLED-based devices were grown rapidly and so on.	[52]
1976	Thomas P. Pearsall invented a new semiconductor material having exceptionally bright LED and high efficiency in lieu of usage in fiber optics and telecommunications.	[5–8]	2016	OLED Display Forecasts 2016–2026: The up-to-date development in plastic and flexible display technology analysis. With reference to a deep profundity of the technological analysis and the remaining logjams, IDTechEx has predicted all types of OLED display flea market toward its future prospects.	[53]
1987	Using AlGaAs (aluminum gallium arsenide) diodes, the Hewlett Packard has produced the first application, encompasses lighting and usage of light bulbs in vehicles brake light, traffic lights and so on.	[5–8]	2017	OLED technology delivers three decades of display innovation with high brightness.	[54]
1989	Cree Inc. declared the first commercially accessible blue LED based on indirect band gap silicon carbide (SiC) semiconductor.	[5–8]	2018	Owing to its intrinsic benefits and upcoming prospect OLED has been applied to widespread applications. Nowadays, OLED is widely employed in smart mobile phones, notebooks, smart watches, TV, visual reality (VR) devices, smart wearable devices, on-board displays, etc.	[55]

Light-emitting diode (inorganic LED)			Organic light-emitting diode (OLED)
1991	Masayuki Senoh, scholar at NICHIA is successful in fabricating p-type gallium nitride (GaN).	[5–8]	
1991	A multi-LED-chip methodology in which the light emitted from three LED chips emitting the three primary colors (red, green, and blue) is mixed to generate white light.	[18]	
1994	Using p-n junction gallium nitride (GaN), the first high illumination blue LED was fabricated by Shuji Nakamura of Nichia Corporation.	[5–8]	
1995	Using indium tin oxide (InSnO), a transparent contact LED was made by Alberto Barbieri.	[5–8]	
1999	PHILIPS LUMILEDS launched power LEDs accomplished of incessant usage by the side of one watt.	[5–8]	
2002	LUMILEDS made 5 WATT LEDs having a luminous efficacy of 18–22 lumens per watt.	[5–8]	
2006	The first LEDs about 100 lumens per watt are manufactured.	[5–8]	
2008	BILKENT University reports the luminous efficacy about 300 lumens per watt from the visible light and warm light by means of nanocrystals.	[5–8]	
2009	CAMBRIDGE University bangs a method for making silicon-based gallium nitride LEDs.	[5–8]	
2010	LEDs of a definite color with a gargantuan luminous efficacy of 250 lumens per watt are heretofore being technologically advanced under laboratory circumstances.	[5–8]	
2010	Solid-state lighting (SSL) is a developing field that potentials enactment features and efficiencies are to use and to harvest enormous extents in terms of energy-economics perspective.	[19, 20]	

Light-emitting diode (inorganic LED)			Organic light-emitting diode (OLED)
From 2010 onward	High luminous efficiency and, consequentially, low power consumption (67 lm/W, Philips, 2010;	[21]	
	94 lm/W, Philips, 2010; commercial LED light bulbs with source efficacies >100 lm/W, by multiple manufacturers, 2015).		
2011	Elgala et al., discussed about the optical wireless (OW) as a capable balancing technology for RF technology has grew newfangled impetus powered by noteworthy utilizations in solid state lighting technology.	[22]	
2014	The Cree Company declared a laboratory-result efficacy of 303 lm/W for a white LED lamp (excluding power supply) with a related color temperature of 5150 K at an injection current of 350 mA.	[23, 24]	
	The OSRAM Company proclaimed a lamp efficacy of 215 lm/W and a system efficacy (including power supply) of 205 lm/W for a white LED lamp system along with a color temperature of 3000 K.		
2014	Zhang et al. showed that the phosphor-in-glass-based white LED shows not only have remarkable features like heat- and humidity resistance, in addition to that it possess high luminous efficacy of 124 lm/W with a correlated color temperature of 6674 K and a color rendering index of 70.	[25]	
2015	The commercial, Light Fidelity (Li-Fi) is designated as a Visible Light Communications (VLC) system running wireless communications itinerant at very extreme haste. The process is by a rapid adoption of indoor and outdoor solid-state lighting will serve as a powerful platform for a new means of delivering data (swaggering speeds of up to 224 gigabits per second approx.) visible light communication (VLC) or Li-Fi.	[26]	

Light-emitting diode (inorganic LED)			Organic light-emitting diode (OLED)
2016	LED Technology Breakthroughs: There were many exciting and surprising technology breakthroughs, based on statistics compiled by LED inside there were at least 10 major technology advancements this year.	[27]	
2017	K. P. Acharya et al., have demonstrated on the high efficiency colloidal quantum dot-polymer hybrid light emitting diodes (QLEDs) that show external quantum efficiencies >12% for all the three primary colors (21% from green) from a positive aging effect (the efficiency of the QLED gets augmented with time).	[28, 29]	
	In the market, nowadays world's top LED-based device manufacturing companies like CREE, NICHIA, Toyoda Gosei, OSRAM, Lumileds (Philips), Seoul Semiconductor, LG Innotek, Edison Opto., EPISTAR, Seoul Semiconductor, San'an Optoelectronics, Sony, Samsung and so on, making high brightness LEDs, LED chips, HD-TVs with excellent lumens output, durability and lifetime, etc.		

Table 1. Historical developments in LED and OLED.

white-phosphor-based LEDs. Also, it could be found that general lighting applications using OLEDs with a rating 50 lm/W [53–55].

2. Recent space-age advancements of LED and its phototoxic-cum-bactericidal effect of blue LED irradiation

In the past few years, incredible developments have been made in LED technologies. In the ambience of lighting industry, LED technology forms one of the energetic forces besides new lighting notions and applications. The accelerated change produce in product design yields the respective powerful light sources. One of the more fundamental advancements, which has promise in the LED arena, is from the nanotechnology referred to as "quantum dots." Being make a breakthrough in efficiency, the respective ultra-small crystals would possess unique

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properties that could be tuned to emit light covering the visibility spectrum. This is highly important because when these particles are in a confined state, they would have the potential to provide diverse options for color for a while producing an improved white. The uniformity, quality, and tonal color of an LED source desperately add to its allure in usage in commercial production applications. Color stability in fact is one of the more accelerating developments seen recently. Using inorganic packaging associated with flip-chip mounting, the features of the phosphor layer are matched to each chip's individual characteristics. As a result, firms could now suggest white LEDs that have a highly precise prefixed color temperature without the discarding necessary to account for natural changes in color. Another significant advancement in LED technologies has to be done with the material which is in the usage in their production and the resulting efficacy of that production. With one emerging technology, LED lighting could be made with a mixture of organic and inorganic materials. The cumulative effect of this technology is somewhat than typical four or five layers of material would be necessary in producing the product; this new material necessitates just one layer. This vividly lowers the cost of production and produces the manufacturing process relatively easier. This is yielding lower cost for LED light sources while performance continues to enhance. This emerges the new technology to more and more potential applications all over the time [56].

A recent study of the bactericidal and phototoxic effect of blue LED irradiation revealed that LED irradiation persuades apoptosis by triggering a mitochondria-mediated pathway and reducing the preliminary growth rate of melanoma cells [57]. Oh et al. observed that irradiation with blue LEDs abridged cell feasibility and thus persuaded apoptotic cell death with the mouse A20 and human RAMOS B-cell lymphoma cells [58]. As a potential risk of high energy LED lamps, lighting at night may disturb the body's biological clock, the circadian rhythm. According to the Harvard Health Letter "Blue light has a dark side," the blue wavelengths seem to be the most harmful at night and comprise a large portion in the emission of CFLs and LED lamps [59, 60].

3. Conclusion

The promulgation of LED lighting has led to prompt progressions in LED lighting technologies over the past few eons across the globe with state-of-the-art scientific advancements; however, evidences besides authenticates that it has been and will spread out to be vitally important in the direction of revolutionary investigation against innovative applications for the societal cause. Among the most important notable advancement in sundry fields of LED and OLED has the roadmap for flexible OLEDs points to the emergence of foldable, rollable displays and the espousal of OLED in smart mobile phones will reach more than 70% by 2020 [54], and this will probably too occur in tablets, laptops, and televisions with subsequently more rapid OLED market share growth. However, the difference of opinion on the bactericidal and phototoxic effect of blue LED irradiation, associated to such parts that need remain to be enhanced for these groundbreaking global improvements on harmful free lighting for the global cause. Thus, studies on peerless LED/OLED hi-tech environs might give way to the future harbingers of green energy in the upcoming scenario.

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Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this chapter.

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